Understory

Moderator:

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PRELIMINARY RESULTS: EFFECTS OF FERTILIZATION, HERBICIDE APPLICATION, AND PRESCRIBED BURNING ON UNDERSTORY REGENERATION ON PINE PLANTATIONS IN EAST TEXAS

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Abstract —Biodiversity and species rareness are increasingly the focal points for assessment of habitat quality. Managed pine plantations are often viewed as monocultures with little of value beyond their timber crop. The purpose of this study is to assess vegetative biodiversity in the understory of two pine plantations in which different vegetative control mechanisms are being evaluated. Controlled burn, herbicide treatment, and a combination of both are being compared on fertilized and unfertilized plots on two loblolly pine (*Pinus taeda*) plantations in east Texas. This study will compare species diversity and frequency on untreated and treated plots. One-square meter quadrat samples will be evaluated from 0.04 ha sampling plots within 0.1 ha treatment plots. Species richness will be determined as the number of species in each treatment plot. Shannon Index of Heterogeneity will be determined for each treatment. Comparison of different treatments will be made based on species richness and the Shannon diversity indices. Results for the first growth season after treatment will be presented.

INTRODUCTION

Preserving biodiversity has increasingly been recognized as an important management objective in both natural and planted stands (Carey and Curtis 1996; Franklin 1988, Hansen and others 1991; Roberts and Gilliam 1995). The Society of American Foresters recommends management of forestlands to "conserve, maintain, or enhance" biological diversity (SAF, 1991). Maintenance of biodiversity is a value often attributed to good forestry practice, at least on public lands.

Private land owners may become increasingly sensitive to the impact of silvicultural treatment on understory biodiversity as a consequence of increased public attention focused on this value. Limited studies have shown understory biodiversity in managed plantations to be comparable in some cases to that found in naturally reforested areas (Graee & Heskjaer 1997); other studies have shown reduced biodiversity (Hansen and others 1991). It is intuitively obvious that understory diversity will increase when deforested areas are planted in trees, even if the overstory is a monoculture (Lust and others 1998). Comparison of pine plantations to deforested areas would likely show greater biodiversity in the plantations. Further, the plasticity of crop trees such as *Pinus taeda* allows establishment on a variety of sites, which will show major differences in understory communities even though the overstory is homogeneous. Adding to the potential variability is the variation in canopy cover due to management processes such as thinning. In comparison to an undisturbed forest stand, a planted stand after row thinning can have considerably more light reaching the understory, creating more heterogeneity on the forest floor. Other management strategies could also affect understory biodiversity. Pine plantations thus are a potentially valuable natural resource in terms of vegetative biodiversity in the understory species.

This study was undertaken to determine the effect of treatments applied for the crop trees on the understory species richness, species diversity, and ground cover, as measures of biodiversity. Treatments included fertilization, prescribed burning, and herbicide application. The effect of applying herbicide was not analyzed after the first year.

MATERIALS AND METHODS

Field Setup

Two sites were selected in Cherokee County south of Alto, Texas, based on similarities in time of planting and thinning of loblolly pines. On each site, five replicates were established. Within each replicate, eight 0.10 ha treatments plots were set up with ten-meat buffer strips between treatment plots. Nested at the center of each treatment plot is a 0.04 ha measurement subplot.

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TABLE 1— Species Lists for Cherokee Ridge and Sweet Union

FERNS

Common Name	*Scientific Name*	*Site(s)*
royal fern	*Osmundia regalis*	CR
cinnamon fern	*Osmundia cinnamomea*	CR
brackenfern	*Pteridium aquilinum*	CR
FORBS		
common ragweed	*Ambrosia artemisifolia*	CR,SU
flowering spurge	*Euphorbia pubentissima*	CR,SU
yellow wood sorrel	*Oxalis stricta*	CR,SU
butterfly pea	*Centrosema virginianum*	CR,SU
black snakeroot	*Sanicula Canadensis*	CR
croton (goatweed)	*Croton capitatus*	CR
dewberry	*Rubus* spp.	SU
blackberry	*Rubus argutus*	CR,SU
dogfennell (cypressweed)	*Eupatorium capillifolium*	CR,SU
late boneset	*Eupatorium serotina*	CR,SU
selfheal	*Prunella vulgaris*	CR,SU
fleabane	*Erigeron strigosus*	CR,SU
partridge pea	*Chamaecrista fasciculate*	CR,SU
lyreleaf sage	*Salvia lyrata*	CR
American black nightshade	*Solanum americanum*	CR
butterfly milkweed	*Asclepias tuberosa*	CR
wild onion	*Allium canadense*	CR
skullcap	*Scutellaria integrifolia*	CR
bitter sneezeweed	*Helenium amarum*	SU
elephant's foot	*Elephantopus tomentosus*	SU
geranium	*Geranium carolinianum*	SU
horse nettle	*Solanum carolinense*	SU
tropic croton	*Croton glandulosos* var. *septentrionalis*	SU
Sub-shrubs		
green wild indigo	*Baptisia sphaerocarpa*	CR,SU
St.Andrew's cross	*Hypericum hypericoides*	SU
Common Shrubs		
American beauty berry	*Callicarpa Americana*	CR, SU
southern wax myrtle	*Myrica cerifera*	CR
plainleaf sumac	*Rhus copallinum*	CR,SU
eastern bacchcaris	*Baccharis halimifolia*	CR
devil's-walkingstick	*Aralia spinosa*	CR
Small Trees		
yaupon	*Ilex vomitoria*	CR,SU
winged elm	*Ulmus alata*	CR,SU

TABLE 1, continued— Species Lists for Cherokee Ridge and Sweet Union

Common Name	*Scientific Name*	*Site(s)*
American holly	*Ilex opaca*	CR,SU
tree sparkleberry	*Vaccinium arboreum*	CR,SU
rusty blackhaw	*Viburnum rufidulum*	CR,SU
eastern redcedar	*Juniperus virginiana*	CR,SU
sweet bay magnolia	*Magnolia virginiana*	CR,SU
sassafras	*Sassafras albidum*	CR
persimmon	*Diospyros virginiana*	CR
parsley hawthorn	*Crataegus marshallii*	SU
flowering dogwood	*Cornus florida*	SU
Canopy Trees		
sweet gum	*Liquidambar styraciflua*	CR, SU
water oak	*Quercus nigra*	CR, SU
post oak	*Quercus stellata*	CR
blackjack oak	*Quercus marilandica*	CR
black gum	*Nyssa aquatica*	CR
willow oak	*Quercus phellos*	CR
mockernut hickory	*Carya tomentosa*	CR
southern red oak	*Quercus falcate*	SU
white oak	*Quercus alba*	SU
willow oak	*Quercus phellos*	SU
Vines		
poison ivy	*Toxicodendron radicans*	CR,SU
greenbriar	*Smilax* spp	CR,SU
Virginia creeper	*Parthenocissus quinquefolia*	CR,SU
mustang grape	*Vitis rotundifolia*	CR,SU
peppervine	*Ampelopsis arborea*	CR,SU
Alabama supplejack	*Berchemia scandens*	CR,SU
trumpetcreeper	*Campsis radicans*	CR
clematis	*Clematis* sp.	CR

At the site referred to as Cherokee Ridge, a total of 78 hectares were planted in 1985 and row-thinned to a BA of 13.1 m2 ha -1 in 1998. At the outset of the study, soils were classified as Darco, Teneha, and Osier. The topography of the research area is relatively flat upland with mild slopes.

At the site referred to as Sweet Union, 45 hectares were planted in 1982 and row-thinned to a BA of ~ 22.3 m^2/ha in 1998. Soils were classified as Attoyac and Ruston. The topography is similar to the Cherokee Ridge site.

Vegetation Surveys

Four random quadrats within each treatment block were inventoried in April or May, 1999 and again in June or July, 1999. Ground coverage was recorded by class (trace; 1 – 5 percent; 6 – 10 percent;11- 20 percent; 21 – 50 percent; 51 – 75 percent; 76 – 95 percent; 96 – 100 percent) for each vegetation class (species or genus for herbaceous and woody dicots; collectively for graminoids), and number of individuals was recorded for each species of forb, sub-shrub, shrub, vines, small tree, and canopy tree. An individual could be a single stem, a bunch, or a cluster, depending on growth form. Flowering specimens were collected for taxonomic identification. Additional data recorded but not analyzed for this paper includes litter and coarse woody debris (percent coverage using the same classification as ground cover) and percent canopy cover directly over each sampling quadrat. A species list was compiled for each site.

Identical surveys on random quadrats were conducted in late May – early June, 2000. Severe drought precluded sampling in July; most plots showed little growth and most forbs were wilting and dying in July.

Treatments

Herbicide was applied in October, 1999. Accord and Chopper tank mix was applied with a backpack sprayer. At Cherokee Ridge, the mix consisted of 4.5 L Chopper and 2.2 L Accord suspended in 11.2 L Sun-it oil with 76.7 L water per Ha. At Sweet Union, the amount of Accord was increased to 2.5 L. Larger trees were treated with 100 ml of Arsenal AC in 300 ml of water using the “hack-n-squirt” method.

The prescribed burn was conducted during March, 2000 after installing firelines the previous winter. Backfires prevented the spread into most buffer zones, or at least into the next treatment plot. Fertilizer was applied in April, 2000. Urea was applied at a rate of 224 kg/ha N and Diammonium Phosphate (DAP)at a rate of 28 kg/ha P.

Statistical Analysis

Statistical comparisons were conducted using The SAS System (version 8 for Windows). Analysis of variance was determined using General Linear Model Analysis (alpha level of 0.1) to evaluate any changes in species richness or homogeneity, or percent ground cover due to treatments as well as species-specific responses to treatments. Comparisons were based on measures of species richness (number of species per treatment plot, combined for all four sample quadrats per plot), species diversity (using the Shannon index), and percent ground cover classification recorded for each taxon in each quadrat.

Pre-treatment Analysis

Comparisons between sites and between treatment plots were made to determine between-site and within-site homogeneity.

Post-treatment Analysis

Post-treatment analysis consisted of comparing fertilized to unfertilized plots, and burned to unburned plots, as well as looking for interaction between these two treatments. Additionally, comparison between 1999 data and 2000 data were made on each plot. Effects of herbicide were not analyzed after the first year, as most plots with herbicide applied showed little understory growth in the summer after treatment.

Response to treatment of specific species was also analyzed. Frequent species were selected for analysis, including American beauty berry(*Callicarpa americana*), late boneset(*Eupatorium serotina*), poison ivy (*Toxicodendron radicans*), and yellow wood sorrel(*Oxalis stricta*). These species were selected due to their ubiquity at both sites, in many of the plots analyzed, compared to the other species on the list (nearly 100 in all).

RESULTS

Pre-Treatment Site Comparisons

No significant differences were found in either pre-treatment species richness ($P = 0.1026$) or species diversity ($P = 0.1142$) between the two sites.

Species lists for both sites are shown in table 1. While species-specific variability between and within sites clearly exists, no analytic examination of these differences was carried out at this point.

Pre-Treatment Plot Comparisons

No significant differences were found in pre-treatment species richness or species diversity for eight of the ten plots. Plots designated 1 and 3 at Cherokee Ridge had significantly lower species richness ($P < 0.0001$) and species diversity ($P = 0.0003$) than all other plots. These two plots bordered the stream bed; the lowest subplots were significantly wetter in the spring than all the other subplots and had a greater percent of coverage by grass, with fewer trees. The subplots above the bottom had greater slope than all other plots. Significant drought over the last three years could have had a greater impact on these two plots than all the others. Specific values for species diversity and species richness are shown in table 2.

Post-treatment Analysis

No significant difference was found ($P = 0.53$) in total number of individuals per species per plot, species richness, or species diversity, between treatments. A significant reduction in percent ground cover class was identified in plots treated with prescribed burning but not fertilized ($P < 0.0001$). No significant difference was found

Table 2—Species Richness and Shannon Diversity Indices of Pretreatment Plots

Plot	Species Richness	Shannon Index
CR-5	15.375	0.99652
SU-5	15.250	0.89729
SU-2	12.500	0.89382
CR-2	12.625	0.88817
CR-4	13.375	0.86574
SU-1	11.000	0.86515
SU-4	10.250	0.85264
SU-3	9.875	0.80688
CR-3	6.000*	0.68288**
CR-1	6.000*	0.63308**

*indicates significantly different values ($P < 0.0001$).
**indicates significantly different values ($P = 0.0003$).

in the number of individuals, between treatments, for the five selected species.

CONCLUSIONS

Change in Measures of Biodiversity

Species richness and species diversity in understory vegetation appear, on the basis of these preliminary results, to be unaffected by the treatments applied to increase growth in the planted pine overstory.

Response of Ground Cover

There is a significantly lower percent ground cover on plots that were not fertilized after burning, compared to plots that were fertilized after burning and compared to unburned plots, with or without fertilizer. Fertilizer alone did not significantly increase percent ground cover, nor did the prescribed burn significantly alter percent ground cover on fertilized plots. Only on unfertilized plots did the prescribed burn reduce percent ground cover in the same year as the burn.

Based on these first-year results, foresters could predict that treating plots with prescribed burning alone can reduce understory ground cover in the following growing season, while treating plots with fertilizer alone will not affect ground cover, and applying fertilizer to burned plots can offset the effect of burning on ground cover.

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STRUCTURE AND COMPOSITION OF VEGETATION OF LONGLEAF PINE PLANTATIONS COMPARED TO NATURAL STANDS OCCURRING ALONG AN ENVIRONMENTAL GRADIENT AT THE SAVANNAH RIVER SITE

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Abstract—Fifty-four plots in 33-43 year old longleaf pine plantations were compared to 30 remnant plots in longleaf stands on the Savannah River Site in South Carolina. Within these stands, the structure and composition of primarily the herb layer relative to a presumed soil moisture or soil texture gradient was studied using the North Carolina Vegetation Survey methodology. Data were also collected on soils and landform variables. Based on ordination and cluster analyses, both plantation plots and natural stand plots were separated into three distinct site units (xeric, sub-xeric, and sub-mesic). The plantation plots had an overall classification rate of 78 percent while the natural plot classification rate was 87 percent. The xeric end of the gradient demonstrated the most similarity between the remnant and plantation plots. Among all the plots, presence or absence of a B horizon was the most discriminating environmental factor. On the plantation sites, 265 species were found as compared to 297 species on the remnant natural sites. Overall species richness was significantly greater on the remnant sites with a mean of 74.00 species per 0.1 hectare compared to 57.11 for the plantation sites. However, of the 265 species found on plantation sites, roughly 90 percent were judged to be representative of natural or native longleaf pine communities. This lack of a major compositional difference between xeric plantation and natural longleaf sites suggests that restoration of the herbaceous layer may not be as complex as once thought. This provides reasonable encouragement for the restoration of the longleaf pine ecosystem.

INTRODUCTION

The decline of the longleaf pine ecosystem has been well documented. Longleaf pine once dominated as much as 92 million acres throughout the Southeastern United States (Frost 1993). This natural range covered most of the Atlantic and Gulf Coastal Plain regions, from southeastern Virginia to eastern Texas and south into the northern two-thirds of Florida, with extensions into the Piedmont and mountains of northern Alabama and northwest Georgia (Landers and others 1995). Recent estimates show that there may be as little as 3.2 million acres of natural longleaf pine left (USDA Forest Service, Forest Inventory and Analysis, unpubl. data). For this reason, there has been an increase in the efforts to sustain the natural longleaf stands that remain and to restore these ecosystems on a portion of the sites from which they have been extirpated (Mitchell and others 1997).

There is a growing interest in the structure and composition of pine plantations and how they compare to natural longleaf stands. This information is needed to assess the potential for restoration and to develop protocols for restoration. Information about the distribution of longleaf pine communities along environmental gradients (e.g. Christensen 1988, Harcombe and others 1993, Peet and Allard 1993, Jones and others 1984) is available, but little has been published regarding the composition and structure of plantations relative to the same environmental gradients.

This study describes current vegetation patterns and relationships on disturbed plantation sites and compares them to natural, or relatively undisturbed, longleaf pine stands at the Savannah River Site. Sample sites were mostly pine dominated upland sites. Keeping in mind that the ultimate management goal of these plantation sites is restoration to their “natural” state, an understanding of the historical/natural ecosystem conditions, current conditions, and processes that affected the changes is required (Walker and Boyer 1993).

STUDY AREA

The Savannah River Site (SRS) is a 192,323-acre circular tract of federal land that occupies parts of Aiken, Barnwell, and Allendale Counties, South Carolina (Cooke 1936). It is located northeast of the Savannah River on the upper Atlantic Coastal Plain of South Carolina. The Savannah River Site (SRS) has three major geologic/ physiographic regions. These regions are the sandier, excessively drained and droughty areas called the Sandhills Region, the more productive sandy loams and loamy soils of the Upper Loam Hills Region, and the more fertile, well-drained soils of the Red Hills Region (Myers and others 1986). Present vegetation at the SRS largely reflects past disturbance or manipulation by man and is distributed across a moisture gradient extending from xeric, droughty, deep sandy ridges to hydric,

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flooded marshes and swamps (Jones and others 1981, Van Lear and Jones 1987). These disturbed sites are old fields that were the result of intensive agriculture and subsequently replanted with pine, less intensive agricultural sites that were left to regenerate naturally, cutover forests that have had a continuous forest cover of scrub oak/pine, and areas where the natural fire regime has been altered or suppressed.

METHODS

Site Selection

Fifty-four plantation sites were selected at the SRS by using a predetermined set of criteria. Sites must have been (1) dominated by longleaf or slash pine only, (2) planted between 1955 and 1965, (3) located on one of three different soil moisture classes, and (4) burned at least once within the past five years. This method of site selection was accomplished through the use of Geographical Information System (GIS) ARC/INFO software from the Savannah River Forest Service-GIS laboratory. Because too few longleaf pine plantations were available, slash pine plantations on sites originally dominated by longleaf pine were incorporated into this study to increase the sampling area. Because prior history and site preparation methods were similar, consistency between slash and longleaf ground vegetation was expected.

Thirty natural longleaf pine stands were located at the SRS using a variety of methods. First, candidate stands were identified in an inventory by Cecil Frost, Plant Ecologist, North Carolina Department of Agriculture. Additional plots were located using information from local botanists, ecologists, United States Forest Service personnel, GIS software, satellite imagery, digitized maps linked to databases, and reconnaissance work in the field to locate other suitable natural stands. Criteria used to help determine natural vegetation included, but were not limited to (1) observations of vegetation structure, by layer, under known fire regimes, (2) presence of remnant fire frequency indicator species, (3) presence of remnant fire frequency indicator communities, and (4) known historical records of remnant or natural areas (Frost 1997).

Field Sampling

Plot size for most North Carolina Vegetation Survey (NCVS) plots was 20 x 50 meters (1000m^2 or 0.1 hectare). An alternative configuration of 20 x 20 meter (400m^2) plots was used for sampling several of the natural longleaf stands. This alternative plot size was necessary due to the relatively small patches of natural longleaf pine scattered throughout the Savannah River Site. Using a smaller plot size (400m^2) was the only method available to ensure homogenous sampling of natural vegetation. This alternative plot size (400m^2) is within the size range recommended by Mueller-Dombois and Ellenberg (1974) for sampling forest vegetation. The widespread use of these NCVS plots in a variety of forested vegetation types and the consequent availability of substantial comparative vegetation data at this scale led to the adoption of these plot sizes.

The NCVS (Peet and others 1998) uses a modular approach for sampling. Within each 0.1 ha (1000 m^2) plot, there was a 2 x 5 array of 10 x 10m modules (100 m^2 or 0.01 hectare). Within this 2 x 5 array of modules, there was a prescribed block of four focal modules (in a 2 x 2 array). The focal modules were intensively sampled. An aggregate count of woody stems was made in the remaining six modules, and this area (600 m^2) was searched for species not encountered in the four focal modules measured previously. In the alternative configuration of 400m^2 plots, all four modules were treated as focal modules and intensively sampled according to NCVS methodology.

Soil samples for chemical analysis were collected in the center of each of the focal. For each sample a core of mineral soil to a depth of 10 cm was collected for chemical analysis. Soil samples for textural analysis were collected in the middle of the plot along the midline. A sample of the A and B or C horizon was collected and depth to maximum clay and depth of litter layer recorded. The soil series and a description of the soil profile were also recorded. Soil samples were analyzed by Brookside Labs (308 S. Main St., Knoxville, OH 45781).

Data Analysis

A series of multivariate techniques was used for data analysis. Detrended Correspondence Analysis (DCA) (DECORANA, Hill 1979a), was on used to analyze vegetation data (McCune and Mefford 1999). DCA or DECORANA© is an ordination program that ultimately displays stand and/or species data in multidimensional space (Hill 1979a). The distance between stands or species indicates the relative degree of similarity or difference (Hutto and others 1999).

Cluster analysis of vegetation was performed by Two Way Indicator Species Analysis (TWINSPAN, Hill 1979b). TWINSPAN© is a polythetic diverse classification that simultaneously classifies both species and plots using the main matrix for vegetation data (McCune and Mefford 1999). TWINSPAN was used in conjunction with DCA to reduce this subjectivity in delineating groups of similar plots. TWINSPAN was also used to identify indicator or diagnostic species that were strongly correlated to a certain community association.

Stepwise discriminant analysis and discriminant analysis techniques were used to identify those environmental variables which best described the stands which had already been placed into groups by ordination and classification(Afifi and Clark 1990). Soil and landform variables were used in the analysis. Stepwise discriminant analysis was used to determine which of these variables were significant at the 0.15 and 0.20 level of significance for plantations and natural sites respectively. Discriminant analysis was then used to accurately predict site unit membership using the discriminating environmental variables that were identified for both plantation and natural stands.

Standardized t-tests at the 0.05 level of significance were used to test for significant differences between plantations and natural stands. Mean environmental and physical

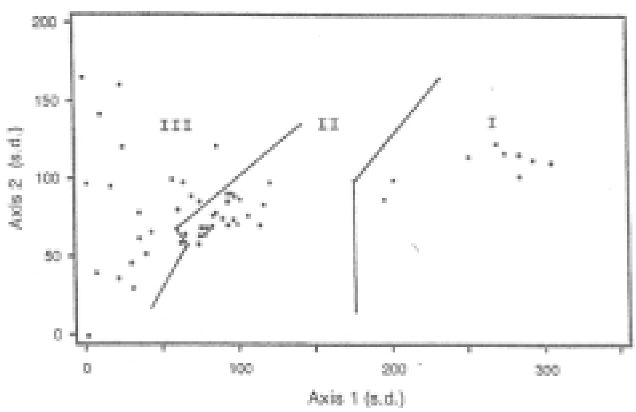

Figure 1—Ordination of 54 plantation plots using full importance values.

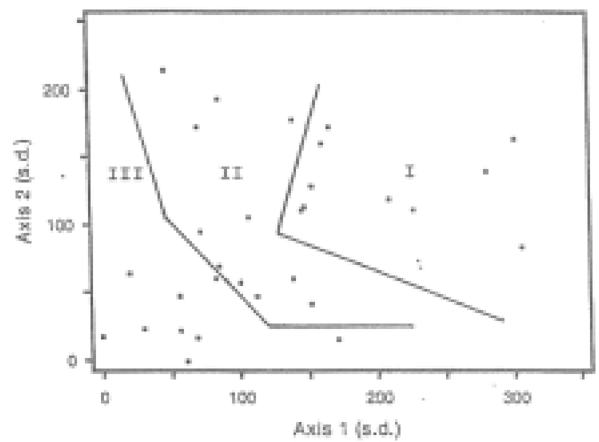

Figure 2—Ordination of 30 natural plots using full importance values.

variables as well as species abundances were tested for significant differences between plantation and natural sites occurring on similar soil moistures.

RESULTS

Plantation Sites

The primary data matrix for plantation sites consisted of 54 plots and 265 species. The ordination Axis 1 was related to a soil moisture gradient (figure 1). Based on ordination and cluster analysis, the plots were separated into three groups. Plots near the origin of the graph exist on the extreme xeric end of the soil moisture gradient, while plots near the end of the graph exist on the more mesic end of the gradient. Groups were labeled I, II, and III, with I on the mesic and III on the xeric end of the gradient. There was also some variation among plots on the xeric end of Axis 2. The source of this variation has not been determined, and is most likely the result of some disturbance due to previous land use.

Of the fifteen environmental variables used in stepwise discriminant analysis, three significant variables were found at the 0.15 level of significance for plantations. These variables were (1) presence/absence of B horizon, (2) soil pH, and (3) percent sand in B or C horizon.

Discriminant function analysis determined the classification success rate for each ecological site unit or group. The resubstitution success rate was 81 percent and misclassified a total of eight plots. The cross-validation success rate was 78 percent and misclassified nine plots.

TWINSPAN was used to find indicator species for each group of plantation sites identified. Generally, an indicator species is a species of narrow ecological amplitude with respect to one or more environmental factors (Allaby 1994). For this study, indicator species are defined more loosely as the most characteristic community members and include species typical of and vigorous in a particular environment. Indicator species for group I sites included *Pinus elliottii*, *Pinus taeda*, and *Chimaphila maculata*. Indicators of group II sites included *Dichanthelium commutatum*, *Desmodium vridiflorum*, and *Centrosema virginianum*. *Quercus laevis*, *Quercus incana*, and *Bonamia patens* were indicators of group III sites.

Natural Stands

The primary data matrix for natural stands consisted of 30 plots and 297 species. Ordination arranged these plots along a soil moisture gradient (axis 1) that showed a beta diversity of 3.5 standard deviations (figure 2). Based on ordination and cluster analysis, these plots were separated into three groups, with plots (group III) near the origin of the graph on the extreme xeric end of the gradient, and plots (group I) near the end of the graph on the more mesic end of the gradient. Axis 2 showed a beta diversity of 2.5 standard deviations.

Of the fifteen environmental variables used in discriminant analysis, eleven were found to be significant at the 0.20 level of significance. These variables were (1) presence/absence of B horizon, (2) landform index, (3) soil magnesium, (4) sodium, (5) calcium, (6) nitrogen, and (7) potassium, (8) organic matter, (9) percent sand in respective horizon, (10) percent clay in the respective horizon, and (11) percent sand in the A horizon.

Discriminant function analysis was then performed to find classification success rates for each ecological site unit or group. The resubstitution success rate was 100 percent. The cross-validation success rate was 87 percent with four plots missclassified.

Each group of natural stands defined by ordination/classification revealed a distinguishable group of vegetation and set of associated physical and environmental variables. TWINSPAN was used to find indicator species for each group of natural stands identified. Iindicators of group I sites include *Quercus stellata*, *Aristolochia serpentaria*, and *Clitoria mariana*. Group II indicators included *Aristida beyrechiana* and *Pinus taeda*. *Opuntia compressa*, *Cnidoscolus stimulosus*, and *Cirsium repandum* were indicators of group III sites.

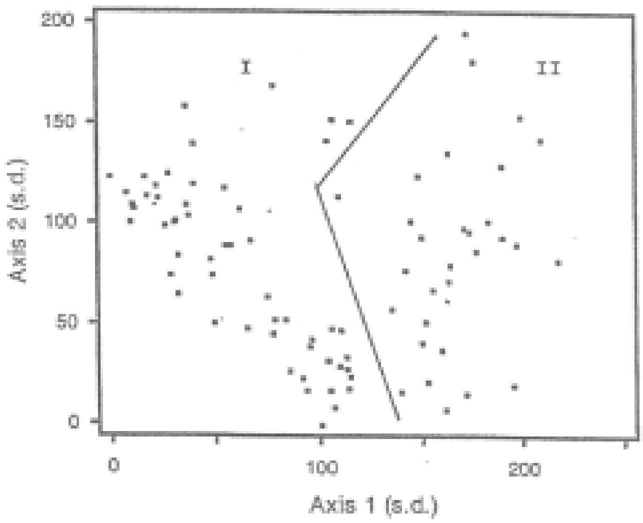

Figure 3—Initial ordination of both plantation and natural plots (n = 84) using species presence/absence values and first order division.

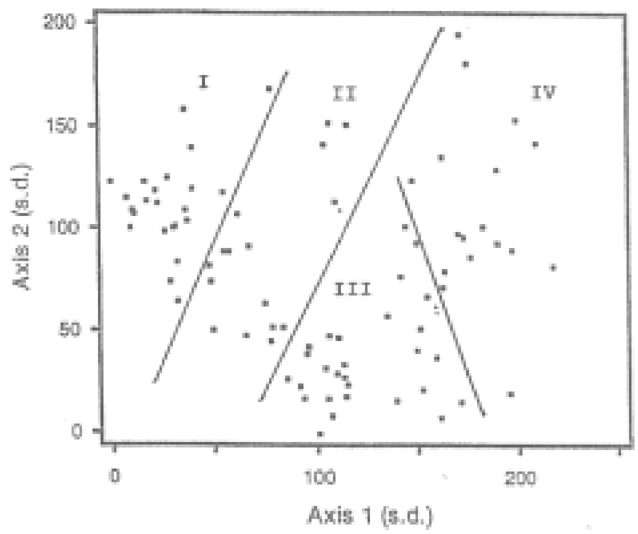

Figure 4—Ordination of both plantation and natural plots (n = 84) using species presence/absence values and second order division.

Plantation Sites Versus Natural Stands

The primary data matrix for both plantations and natural stands consisted of 84 plots and 361 species. Ordination separated all eighty-four plots into two groups (figure 3). These groups corresponded to the first order division of TWINSPAN. Plots were separated into two distinct associations based on origin (plantation or natural). Ordination arranged each of these groups along a distinct soil moisture gradient (axis 1) that showed an overall beta diversity of 2.5 standard deviations. Group I plots were identified as plantation sites and arranged along a soil moisture gradient that has a beta diversity of 1.5 standard deviations. Plots near the origin of the graph exist on the mesic end of the soil moisture gradient, while plots near the center of the graph exist on the xeric end of the gradient. Group II plots were identified as natural stands and arranged along a soil moisture gradient that showed a beta diversity of 1.0 standard deviations. Plots near the center of the graph exist on the xeric end of the soil moisture gradient, while plots near the end exist on the mesic end of the gradient.

The second order of division of TWINSPAN was used to further break down plot groupings. Plots were then separated into four groups (figure 4). These groups exist along the same presumed soil moisture gradients noted above. Groups were labeled I, II, III, and IV. Of the four groups identified, groups I and II were of plantation origin and IV was of natural origin. Group III was the only group of plots that displayed combination of plantation and natural stands (figure 5). Group III occurred on the xeric end of the soil moisture gradient. This would suggest that on the most xeric sites, similar vegetation may exist on both plantation and natural stands. Group III was further divided by the third order of division. Group III_A identifies plots of plantation origin while group III_B identifies plots of natural origin.

Overall mean species richness of plantation sites ranged from a low of 53.44 species per 0.1 hectare on sub-mesic sites to a high of 60.73 species per 0.1 hectare on sub-xeric sites. Overall mean species richness of natural sites ranged from a low of 71.09 species per 0.1 hectare on sub-xeric sites to a high of 76.33 species per 0.1 hectare on xeric sites. The species richness across all natural stands was found to be significantly higher compared to plantations (74.00 versus 57.11 species per plot; t-test, alpha <0.1).

CONCLUSIONS

Three distinct vegetative communities were described for both longleaf plantation and natural sites across a soil moisture gradient at the Savannah River Site. Presence/absence of the B horizon, soil pH, and percent sand in the underlying soil horizons (B or C) were the most discriminating environmental variables separating plant communities on longleaf plantation sites. On natural stands, eleven discriminating variables were used to separate plant communities: the presence/absence of the B horizon, landform index, levels of soil magnesium, sodium, calcium, nitrogen, potassium, and organic matter, and percent sand in respective horizon (A, B, and C horizons). Variables controlling the distribution of vegetation among natural groups are not as clearly defined as plantation groups. The presence or absence of a B horizon was the most discriminating environmental variable discriminating among groups for both plantation and natural stands.

Plots were separated into two distinct associations based on origin (plantation or natural). Further, the most similar groups of plots between plantation and natural stands were those that occurred on the most extreme xeric end of the soil moisture gradient. Although overall species richness was significantly higher on natural stands, vegetation composition and structure on these sites were most similar for both xeric plantations and natural stands. This work suggests that well-burned xeric longleaf plantations that have

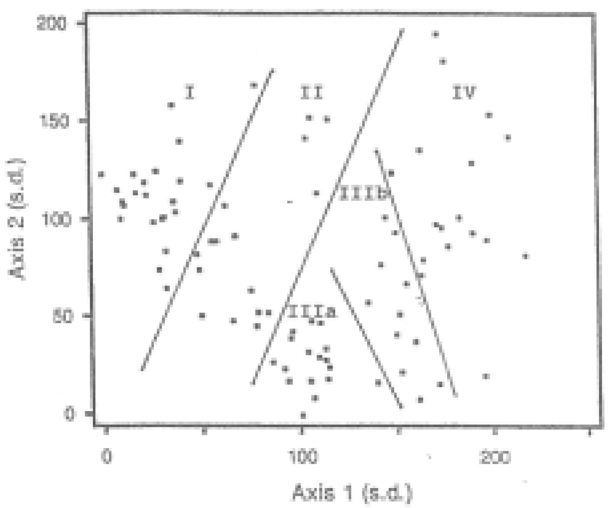

Figure 5—Final ordination of both plantation and natural plots (n = 84) using species presence/absence values.

undergone limited soil disturbance may not be as degraded as previously thought (Noss 1989; Abrahamson and Hartnett 1990).

Out of the 265 species found on plantation sites sampled, about 90 percent were judged to be species representative of natural or native longleaf pine sites. The lack of compositional differences between xeric plantation and natural stands suggests that restoration of the herbaceous layer of longleaf plantations may not be as complex as often thought. Restoration of plantation sites may require the reintroduction of only several native species to the landscape, as well as management practices best suited to maintain natural conditions, such as frequent burning and thinning of the canopy to restore herb vigor.

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UNDERSTORY RESTORATION IN LONGLEAF PINE PLANTATIONS: OVERSTORY EFFECTS OF COMPETITION AND NEEDLEFALL

Christa M. Dagley, Timothy B. Harrington, and M. Boyd Edwards[1]

Abstract—Overstory and midstory vegetation layers strongly limit abundance and species richness of understory herbaceous plants in longleaf pine (Pinus palustris Mill.) plantations. However, the separate effects of overstory competition and needlefall remain unknown and are the subject of this study. Four levels of overstory thinning were applied to 0.10-hectare plots in each of three 13- to 15-year-old plantations at the Savannah River Site, resulting in 0, 25, 50 and 100 percent pine stockings. Four split plots were established within each main plot: trenching (presence or absence) to eliminate pine root competition and needlefall (presence or absence). Containerized seedlings of selected herbs were grown in a greenhouse, planted within each treatment, and their abundance and size were monitored during 1999-2000. Soil surface temperature and availabilities of light, soil water, and soil and foliar nutrients also were measured periodically. Light availability and temperature each decreased with pine stocking, while in specific months, availabilities of soil water and nitrogen were greater in the presence versus absence of trenching. Reductions of seedling performance with increasing pine stocking were less in the presence versus absence of trenching. Certain species demonstrated shade tolerance, while others had optimal growth at 0 percent pine stocking. For several species, cover increased (1999) and then decreased (2000) in response to accumulation of needlefall. Results indicate that plant responses to light availability were strongly regulated by soil water availability and needlefall.

INTRODUCTION

Longleaf pine once dominated one of the most extensive forest ecosystems in North America, but today only 3 percent of its original distribution remains (Landers and others 1995). The primary factors thought to be responsible for the near disappearance of these forests are regenerative failure of longleaf pine, fondness of feral livestock for the seedlings, and fire suppression during the 20th century (Frost 1993).

Natural longleaf pine forests are distinguished by their diverse herb dominated understory communities and associated animal communities (Glitzenstein and others 1993). Fire suppression since 1920 has resulted in the replacement of longleaf pine savannahs with dense, stratified stands of overstory pines, midstory hardwoods, and understory shrubs. In many cases, loblolly pine (*Pinus taeda* L.) has become dominate because its shade tolerance and seed production are superior to those of longleaf pine (Baker and Langdon 1990). In these replacement stands, midstory hardwoods often consist of the turkey oak (*Quercus laevis* Walt.), bluejack oak (*Quercus incana* Bartr.), and blackjack oak (*Quercus marilandica* Muenchh.). Understory vegetation can be large and abundant with species such as sumac (*Rhus spp*.), sparkleberry (*Vaccinium spp*.), and waxmyrtle (*Myrica cerifera* L.). In addition, vine species such as Japanese honeysuckle (*Lonicera japonica* Thunb.), yellow jessamine (*Gelsemium sempervirens* St.Hil.), and greenbriers (*Smilax spp.*) invade the site. These conditions reduce light availability in the understory, and thereby limit diversity of associated plant and animal species (Harrington and Edwards 1999, Johannsen 1998).

To restore longleaf pine communities it is often necessary to plant longleaf pine and to reintroduce understory herbs. However, in order for community restoration to be successful, key factors that limit establishment and maintenance of reintroduced understory herbs must be identified. In fall 1998, research was initiated at the Savannah River Site in plantations of longleaf pine to separate and quantify overstory effects for light, water, and needlefall on a variety of native perennial herbaceous species. Results of this research will be used to aid efforts to restore native longleaf pine communities and to improve our understanding of overstory and understory interactions.

METHODS

The study was initiated within three 13- to 15-year-old longleaf pine plantations at the Savannah River Site, a National Environmental Research Park near Aiken, SC. Soils for the three sites (blocks) consist of Lakeland, Troup, and Blanton sands. In October 1998, basal area of overstory pines was thinned to four stocking levels (0, 25, 50, and 100 percent of the average basal area of unthinned stands) in single 0.1-hectare plots at each site. To remove potential confounding influences from non-pine species, this vegetation was eliminated from the plots by periodic applications of non-soil active herbicides, glyphosate and triclopyr. Within

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each stocking level, four 1.2-meter x 13.7-meter split plots were installed to provide a 2 x 2 factorial arrangement of the presence or absence of trenching or needlefall. In the trenched treatments, a Ditch Witch® was used to excavate linear trenches around each split plot to a depth of approximately 0.5 meters. To prevent future encroachment of pine roots each trench was lined with aluminum flashing and then refilled. In the needlefall treatment, controlled levels of needlefall (presence or absence) were applied monthly at a rate equal to twice that of a fully-stocked stand, where monthly needlefall rates were based on existing data from Harrington and Edwards (1999). Each split plot was divided into eleven quadrats of area one square meter within which a single species was planted. One quadrat remained unplanted throughout the duration of the study and was used to measure soil water content. Each quadrat was kept free of all competing vegetation with monthly hand weeding.

A group of native, perennial, herbaceous species that varied in size and growth form was selected for this study (table 1). Seeds of each species were collected at or near the study sites, germinated via cold stratification and their seedlings were grown for four months within containers. In May 1999 and 2000, populations of 36 seedlings per species were planted within the quadrats with a container dibble. Containerized seedlings of longleaf pine also were planted. A total of thirteen species were planted in each of the split plots (eight in 1999 and five in 2000). To provide room for the three additional species of the 2000 cohort, three species from the 1999 cohort were removed in April 2000.

In combination, the thinning and trenching treatments enabled experimental separation of interference from the overstory pines into above- and below-ground components. Likewise, the needlefall treatment was applied independent of pine stocking level, and thus its effects can be quantified separately. Measurements of environmental conditions (crown closure via vertical densitometer, soil water content via time domain reflectometry, available soil nitrogen via KCL extractions, and foliar nitrogen, potassium, and phosphorus content) and soil surface temperature were taken periodically during each growing season. Performance of planted species (survival, cover, height, and biomass) also was monitored during each growing season.

RESULTS

Environmental Conditions

The long-term average growing season (May-October) precipitation for Aiken SC is 66 centimeters (weather.com). Precipitation for the 1999 and 2000 growing season was 56 and 48 centimeters, respectively (Savannah River Forest Station 2000). Although both years were drier than normal, precipitation was sufficient in 1999 at the time of planting. In contrast, rainfall for May 2000 was less than 1.3 centimeters, which negatively impacted survival of seedlings planted in that year. Soil surface temperature declined linearly with pine stocking and the difference between 0 and 100 percent stockings averaged 3.2 degrees Centigrade.

In the two growing seasons since thinning of pines, basal area has increased by 15, 28, and 32 percent in the 100, 50, and 25 percent stocking levels, respectively. In contrast, crown closure has increased at a much slower rate, particularly in the 25 and 50 percent stocking levels where little change occurred from 1999 to 2000. The thinning and trenching treatments had no visually detectable influence on pine vigor except for mortality of two trees that died from unknown causes.

In the absence of trenching, soil water declined consistently as pine stocking increased from 50 to 100 percent. However, in the presence of trenching, soil water availability was influenced very little by pine stocking. These responses indicate that the trenching treatment was successful in partitioning competition from pine into above- and below-ground components. During several periods in the 1999 and 2000 growing seasons, soil water in non-trenched split plots dropped below 6 percent, the assumed permanent wilting point for these soils.

In three of the five months of monitoring, available nitrogen differed significantly among treatments. In June, available nitrogen was greater in the presence versus absence trenching. Available nitrogen in August was less in the presence versus absence of needlefall, while the opposite trend occurred in September.

Plant Responses

Survival of the 1999 cohort was high, averaging greater than 80 percent for the eight species. In contrast, survival of the 2000 cohort was low probably because of the severe spring drought, averaging less than 10 percent for the five species. However, first-year survival of each cohort was greater in the presence versus absence of trenching. During the second growing season, survival of the 1999 cohort was greater in the presence of trenching and absence of needlefall.

The species of the 1999 cohort varied in their patterns of response to the pine stocking, trenching, and needlefall treatments; however, the highest performance was observed when pine stocking was 0 percent. In addition, most species had superior performance in the presence versus absence of trenching. Cover, height, and biomass responses of the 2000 cohort plant could not be analyzed because of poor survival.

Anthaenantia villosa, *Pinus palustris*, *Liatris elegans*, and *Sorghastrum secundum* demonstrated an interactive response pattern. They exhibited excellent performance even under 100 percent stocking of longleaf pine, as long as availability of below-ground resources did not severely limit their growth (i.e., in trenched split plots). However, if below-ground resources were in growth-limiting supplies (i.e., in non-trenched split plots), performance declined considerably as pine stocking increased and associated availability of light decreased. These species also exhibited superior performance in the presence versus absence of needlefall, except at full stocking in non-trenched split plots where needlefall negatively affected species' performance.

Solidago odora, *Pityopsis graminifolia*, and *Lespedeza hirta* demonstrated an additive response pattern to the

Table 1—Species planted in the longleaf pine study at the Savannah River Site

Scientific name	Characteristics
Anthaenantia villosa (Michx.) Beauvois[a]	Ascending perennial grass; short rhizomes
Lespedeza hirta (L.) Hornemann[a]	Erect perennial forb; nitrogen fixer
Liatris elegans (Walt.) Michx.[a,c]	Erect perennial forb; corms
Pinus palustris Mill.[a]	Tree
Pityopsis graminfolia (Michx.) Nutt.[a,c]	Erect perennial forb; rhizomes
Solidago odora Aiton[a,c]	Erect perennial forb; short rhizomes
Sorghastrum secundum (Ell.) Nash[a]	Ascending, tufted perennial grass; short rhizomes
Sporobolus junceus (Michx.) Kunth[a]	Erect to sprawling perennial grass
Andropogon ternarius (Michx.)[b]	Erect perennial grass; short rhizomes
Carphephorus bellidifolius (Michx.) T.& G.[b]	Ascending perennial forb
Chrysopsis gossypina (Michx.) Ell.[b]	Erect, decumbent, or ascending perennial forb
Desmodium ciliare (Muhl. Ex Willd.) DC.[b]	Erect perennial forb
Eragrostis spectabilis (Pursh) Steudel[b]	Erect perennial grass; short rhizomes

[a]May 1999 planting;
[b]May 2000 planting;
[c]Removed

treatments. Species' performance increased as pine stocking decreased and in the presence of trenching; however, the two factors did not interact.

Foliar nitrogen of *Sporobolus junceus* was greater in the presence versus absence of needlefall, indicating a "fertilizer" effect. Per-plant amounts of nitrogen, phosphorous, and potassium increased as pine stocking decreased, a direct result of increases in plant biomass.

CONCLUSIONS

This research has increased our understanding of the complexity by which overstory pines affect understory vegetation through resource competition and needlefall. Performance of most species was increased when availability of below-ground resources was elevated, regardless of pine stocking. In addition, effects of trenching and needlefall interacted with pine stocking level for certain species, indicating that limiting effects of shade can be either moderated or exacerbated by variation in below-ground resources or presence of needlefall. The two response patterns, interactive and additive, provide a means of classifying herbaceous species according to their potential performance in longleaf pine community restoration, given specific overstory, understory, and needlefall conditions of longleaf pine plantations.

Research results indicate that containerized reproduction can be a successful method for restoring herbaceous species if rainfall is adequate at the time of planting. Optimal performance of planted species is likely to occur in large canopy openings with minimal root competition from associated woody and herbaceous species.

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ECOLOGICAL RESTORATION THROUGH SILVICULTURE—A SAVANNA MANAGEMENT DEMONSTRATION AREA, SINKIN EXPERIMENTAL FOREST, MISSOURI

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Abstract—In 1998, a project was initiated to demonstrate techniques and evaluate the efficacy of reducing overstory tree density and reintroducing fire in order to develop the tree composition, structure, and herbaceous complex typical of a savanna. On three study areas, two dominated by oak and one by shortleaf pine, the total basal area of all trees = 1.6 inches DBH was thinned to approximately 40 feet^2 basal area per acre during the 1998-99 dormant season. Prescribed burns were conducted in April 1999 and April 2000. After assessing mortality from the fire, the residual basal area was adjusted to 35 feet^2 per acre during the 1999 growing season.Pretreatment inventories conducted during August of 1998 tallied over 45 herbaceous and woody understory species. During the first-year post-treatment inventory (August 1999), 20 new herbaceous species were identified on the treatment plots. Following the second prescribed fire, 17 additional herbaceous species were tallied (August 2000). The most abundant of these species were fireweed and pokeweed. Of the woody understory species (<1.6 inches DBH) present on the sampling plots, only the oaks and hickories did not exhibit a substantial change in the number of stems per acre following treatment. Blackhaw was eliminated from the understory following the prescribed burn and the numbers of black cherry, red maple, dogwood, and shortleaf pine decreased by more than 50 percent. Species that benefited from the treatment included black gum (+210 percent), sassafras (+40 percent), sumac (+2110 percent), and post oak (+494 percent). Initial treatments greatly modified the overstory structure and, thus, the understory light regime. This in turn has affected an immediate and marked shift in the understory complex of herbaceous and woody plants.

INTRODUCTION

Management and restoration of savannas has become a topic of considerable interest in recent years. These are among the most diverse systems in the Northern Temperate Zone, but have declined in area by over 99.9 percent during the last 100 years (Nuzzo 1986). Much of this reduction has been due to changes in land use across the Midwest (e.g. agricultural conversion). However, in many areas including the Ozark Highlands, over the last 50-100 years fire suppression has caused a marked reduction in small diameter tree mortality. This in turn has affected a change from savanna to closed canopy forest with a corresponding reduction in herbaceous species diversity as understory light levels diminished (Jenkins 1997).

If fire was the primary disturbance factor that maintained savanna ecosystems on the landscape and suppression of this disturbance caused a change in the basic makeup of the system, then one might expect that the reintroduction of fire should restore the ecosystem to its original structure and function. Unfortunately, this has not proven to be the case, at least not within a reasonably short time frame. In an attempt to restore pre-settlement structure and composition in a Missouri oak forest, Blake and Schuette (2000) reported that reintroduction of regular prescribed fires had no effect on overstory species composition or structure after 10 years. Similar results were reported after 15 years in Minnesota (White 1986) and after 20 years in Illinois (Taft and others 1995). Although reintroduction of a fire regime greatly reduced the shrub layer and the number of small diameter trees (Blake and Schuette 2000, White 1986) the effect on large diameter canopy dominant trees was slight. These trees tend not to be affected by low intensity prescribed fire. In order to recreate pre-settlement conditions using fire alone, either higher intensity burns would need to be used (with the associated risk of a stand replacing fire or escape of the burn onto adjacent property) or sufficient time would need to pass for natural mortality to occur within the dominant canopy of the stand. An alternative is to cut or kill a sufficient number of large diameter stems to recreate the desired stand structure immediately.

Restoration ecology may be defined as active management that seeks to return a 'degraded' system to the structure, composition, and disturbance regime of some reference time or ecosystem (after Wagner and others 2000). This 'reference state' is often defined as that which existed pre-European settlement. Thus, restoration ecology actively manipulates a system to achieve a desired vegetative

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Table 1—Pre-treatment overstory measurements

	Basal area (ft^2/acre)	Stocking (percent)	Canopy cover (percent)	Light transmission (percent)
Savanna 1	112.5 ± 11.8	100.2 ± 7.8	80	14.4 ± 12.3
Savanna 2	79.4 ± 7.1	69.6 ± 5.5	71	25.8 ± 28.3
Savanna 3	152.5 ± 22.5	120.2 ± 13.4	99	4.4 ± 3.9

state. In the same vein, silviculture is defined as the art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis (Helms 1998). In other words, active manipulation of forest stands to meet landowner objectives. Wagner and others (2000) suggest that restoration differs from silviculture in that it substitutes a reference condition for specific objectives. This seems to be a difference without real substance. If a landowner lists as an objective the creation of some reference condition, the silviculturist can develop a prescription to achieve that end, subject to the same constraints as any other objective (i.e. is the objective biologically possible, is it mutually exclusive of another stated objective, are there sufficient resources to achieve the stated objective, etc…). Such prescriptions have been written and implemented for restoration of pre-settlement ponderosa pine habitat (Lynch and others 2000) and for creating/restoring optimal goshawk habitat (Long and Smith 2000). As an added bonus, the silvicultural methods used to arrive at the desired vegetative state may generate income to the landowner.

The Sinkin Experimental Forest is used primarily for research and demonstration. This demonstration site was not intended nor was it designed to be a formal experiment or comparison. There is no true statistical replication and the prescribed burns were not implemented or monitored in sufficient detail to draw conclusions about cause and effect. We initiated this project to demonstrate techniques and evaluate the efficacy of reducing stand density and reintroducing fire in order to develop the tree composition and structure and herbaceous complex typical of a savanna/oak-woodland. It was also designed to show small landowners another option for land management where timber production may not be the driving force on a parcel, especially in an area where oak decline is or might be a problem.

Table 2—Post-treatment overstory measurements

		Basal area (ft^2/acre)	Stocking (percent)	Light transmission (percent)
Savanna 1	1999	35.5	33.4	73
	2000	32.8	29.1	74
Savanna 2	1999	26.9	27.4	67
	2000	25.6	24.3	79
Savanna 3	1999	35.3	21.2	75
	2000	29.0	17.4	83

METHODS

Site Description

The savanna demonstration area consists of three separate stands on the Sinkin Experimental Forest, which is located in south central Missouri in the Ozark Highlands. Savanna 1 is approximately 2.75 acres in size and is located on an upper slope with a western aspect. The site index is 60-65 feet (for black oak, base age 50 years) and the pretreatment overstory was composed primarily of black oak, white oak, post oak, and hickory (average age 95 years). The midstory and understory tree species were primarily black gum, dogwood, and sassafras. During the 1998 growing season, this stand supported approximately 108 $feet^2$/acre of basal area (all trees = 1.6 inches DBH) (table 1).

Savanna 2 is 4 acres in size and lies on a southwest facing upper slope. The overstory was dominated by 85-year-old scarlet oak, black oak, white oak, and shortleaf pine. Like savanna 1 the site index was in the low 60's. Understory trees were principally hickory, black gum, and dogwood. This stand had been affected by oak decline, there were several large dead or dying scarlet and black oaks; this reduced standing density to approximately 80 $feet^2$/acre basal area. Because of the relatively low density of this stand, there was a well-developed understory and midstory of oak advance reproduction and woody shrubs.

Savanna 3 covers 3 acres on an upper west-facing slope. It was the only shortleaf pine dominated site. The trees were approximately 80 years old and the site index was estimated at 65 feet. Smaller pole sized trees in this stand included white oak, post oak, black oak, scarlet oak, hickory, black gum, and dogwood. There were few subcanopy or understory trees in this stand, probably due to the high density (153 $feet^2$/acre basal area).

Measurements

In each of the three stands, a pre-treatment inventory of the overstory and understory was made during the 1998 growing season. Three circular one-third acre overstory plots were established on each site and all trees = 1.6 inches DBH were tallied by species and DBH. Post-treatment inventories were conducted during the 1999 and 2000 growing seasons.

Data on all understory woody stems (< 1.6 inches DBH) was collected on 96 one-five hundredth acre circular subplots (24, 36, and 36 plots on savannas 1, 2, and 3, respectively). This vegetation was tallied by species, origin, height class, and number of stems. Herbaceous and semi-woody stems were sampled in a one square-meter frame located at an azimuth of 90 degrees and 2 meters distance from subplot center. All vegetation was tallied by species, height class, and percent cover.

Canopy closure was measured at each subplot center with a densitometer. In addition, canopy photographs were taken using an 18mm lens and PAR (photosynthetically active radiation) was sampled with a sunfleck ceptometer.

Prescription

Our target overstory structure was to have approximately 35 feet^2/acre of large, well-spaced trees. This density would equate to approximately 50 percent canopy closure if the trees had been open grown (Law and others 1994). However, since the initial stands were fairly high density, closed canopy stands, the crowns of the residual stems were less developed than open grown trees and the resulting canopy closure would be reduced. As the residual overstory trees expand their crowns, adjustments to stand density will be made in future years to ensure that canopy closure remains within the 10 to 50 percent range cited as typical for Missouri Ozark savanna systems (Nuzzo 1986).

Table 4—Pre-treatment herbaceous plants inventoried

Species	Species
Virginia creeper	
Desmodium	New jersey tea
Wild grape	False solomans seal
Blackberry	American feverfew
Vaccinium	Horseweed
Carolina rose	Horse mint
Helianthus	False buck wheat
Poison ivy	Panicum spp.
Oxalis	Panicum ravenellii
Carex spp.	Panicum commutatum
Carex complinata	Panicum lanuginosum
Bracken fern	Dittany
Cinquefoil	Pussy's toes
Solidago	Lespedeza
Aster spp.	Broom sedge
Aster turbinellus	Bedstraw
Poverty grass	Corral berry
Wood angelica	Goats rue
Hog peanut	Green briar
Milkweed	Rue anemone
Violet	Flowering spurge
False flax	Meadow parsnip
Virginia snake root	Christmas fern

Following the pretreatment inventory, the three study sites were marked to leave approximately 40 feet^2/acre of basal area in all stems = 1.6 inches DBH. Leaving 40 feet^2/acre allowed for compensation based on mortality caused by logging damage or the prescribed fire. Leave trees were selected based on canopy dominance, species, vigor, and spacing.

Table 3—Understory woody stem density (< 1.6 inches DBH) averaged across all three sites

	Pre-treatment (stems per acre)	Post-treatment burn 1 (stems per acre)	Post-treatment burn 2 (stems per acre)
White oak	711	763	323
Black oak	1593	1033	942
Scarlet oak	407	513	478
Post oak	142	228	844
Hickories	527	561	927
Black cherry	176	92	43
Black gum	619	1169	1918
Red maple	335	132	100
Dogwood	713	314	340
Sassafras	1065	2956	1487
Sumac	38	478	840
Savanna 2 only			
Wild plum	14	24	0
Shortleaf pine	359	85	143

Table 5—Newly occurring herbaceous species following treatment

Species	Species
Fireweed	Black haw
Pokeweed	Fake dandelion
Nightshade	Juncos tenius
Goats rue	Ambrosia
Wild strawberry	Big blue stem
Little blue stem	Partridge pea
Hawk weed	Queen Anne's lace
Kentucky blue grass	Fimbristylis
Skull cap	Dogbane
Wild indigo	Wild geranium
Violet	Prickly lettuce
Wild oat grass	Angle pod
False buckwheat	Trailing milk pea
Aromatic sumac	Horse nettle
Pink wild bean	

The largest trees of the most fire resistant species were preferentially left in the stand. During the 1998-99 dormant season, the three stands were thinned. A horse logger was contracted to conduct the harvest for two reasons. First, the total area treated and the volume removed were relatively small. The logger was willing to bid on this sale and was able to complete the project on our timetable. More importantly, the site impact from horse logging is minimal. The horses are able to maneuver in a partially cut stand better than most skidders (residual stand damage was almost non-existent) and upon completion of the harvest operation, the main skid trail looked more like a backcountry hiking trail than a skid trail.

A prescribed burn was conducted on April 7, 1999. Mortality was assessed and the residual basal area was adjusted to 35^{2}feet/acre in May 1999. A second prescribed burn was conducted in April of 2000. There was difficulty in getting the fire to carry across the stands during the second year burn because of low fuel loads and discontinuous fuels. For this reason, future burns will be conducted every other year following an assessment of the fuel conditions on each site.

RESULTS AND DISCUSSION

Overstory

As was mentioned, our target overstory density was 35 feet^2/acre of basal area. Following initial treatments, savannas 1 and 3 were extremely close to the mark at 35.5 and 35.3 feet^2/acre, respectively (table 2). Savanna 2 is somewhat under stocked because of the large incidence of oak decline on this site in the black and scarlet oak components. This stand had somewhat higher fire related mortality, probably due to the higher fuel loads that were caused by the relatively low initial density and subsequently higher light transmission into the understory, which caused a buildup in understory vegetation.

Notice that the stocking percentage is very different between savannas 1 and 3 even though the residual basal area is nearly the same (table 2). Many smaller diameter stems were left on savanna 1 to meet residual stocking demands, which were able to be met with fewer large diameter stems on savanna 3. This difference in overstory structure will also affect percent canopy closure and light transmittance through the canopy. Unless fire related mortality preferentially affects the smaller diameter trees on savanna 1 in the future, additional thinning may be required in this stand first to maintain the desired open structure.

Some additional mortality did occur between years 1 and 2, but this was likely the result of our current drought exacerbating the oak decline problem rather than a direct result from the prescribed fires. At the end of 2000, the Sinkin Experimental Forest had a cumulative 2-year precipitation deficit of nearly 24 inches from a 50-year average annual precipitation rate of 44 inches (data on file at the Columbia Forest Science Lab, Columbia, MO).

Understory

The prescribed fires caused some marked and immediate changes in the understory (< 1.6 inches DBH) woody components of these stands (table 3). Except for the marginal effect of the removal of the overstory trees on these stems (nothing < 1.6 inches DBH was cut during the thinning operation) the change in density was caused primarily by the prescribed fire. Species that experienced large reductions in numbers include: black cherry (-75 percent), dogwood (-52 percent), red maple (-70 percent), shortleaf pine (- 60 percent), and blackhaw was eliminated from the understory. Similarly, some species greatly benefited from the introduction of fire: black gum (+210 percent), sassafras (+40 percent), sumac (+2110 percent), and post oak (494 percent).

Without regard to the direction of change in woody understory numbers, the general dynamic seems to be similar to that reported by Blake and Schuette (2000). The largest of the understory stems have been eliminated. Although many of these stems are resprouting from the root collar (unreported data), it seems that the recruitment of reproduction into the overstory will be reduced or eliminated with regular prescribed fire. Thus, if the disturbance regime (regular fire) is continued, it should be sufficient to maintain the desired overstory structure. However, it should be noted that episodic fire free intervals will be needed at some time in the future so sufficient reproduction can be recruited into the overstory to replace trees lost to mortality.

Herbaceous Vegetation

Pretreatment inventories tallied over 45 herbaceous and semi-woody understory species (table 4). Following the initial treatment (cut and burn), an additional 20 species were identified on the sites. After the second prescribed burn, another 17 species were found (table 5). Following the first year's treatment, 8 species were eliminated from the study sites: Virginia snake root, poverty grass, corral berry, Christmas fern, bedstraw, meadow parsnip, green briar, and rue anemone. However, during the second inventory following treatment, last 4 of these species once again showed up on our tally.

Fireweed and pokeweed arrived in profusion across all of the study sites following the first year's treatment and increased markedly in prominence following the second prescribed fire. By August 2000, fireweed occurred on 82 percent of our subplots with an average cover of 10 percent. Pokeweed appeared on 21 percent of the plots and averaged 14 percent cover. Six other species were fairly common: nightshade (6 percent of plots, 3 percent cover), little blue stem (13, 5), goat's rue (3,9), hawk weed (8, 3), wild strawberry (6, 3), and hog peanut (5, 3). The speed these sites were colonized was somewhat surprising given the fact that they have been under a closed canopy forest for over 40 years and continuous forest cover currently surrounds them for several miles. Either the seed source for these plants is amazingly persistent in the soil, or they have mechanisms for traveling great distance.

CONCLUSIONS

Silviculture need not have timber production as an exclusive (or even primary) objective. The goal is to produce a forest vegetative state that meets the objectives of the landowner. In the case of restoration, that objective is some historical or reference state. Our objective on this demonstration area was to develop the tree composition, structure, and herbaceous complex typical of a savanna. To achieve this goal, a prescription was designed to re-create the overstory structure typical of a pre-settlement Missouri savanna (Nuzzo 1986) and reintroduce the disturbance regime (periodic fire) that historically maintained the reference ecosystem. Initial treatments greatly modified the forest overstory structure, and reduced the litter layer, midstory and shrub layers, greatly increasing light levels at the forest floor. In turn, this has affected an immediate and marked shift in the understory complex of herbaceous and woody plants, nearly doubling the species diversity within two years of initial treatment.

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